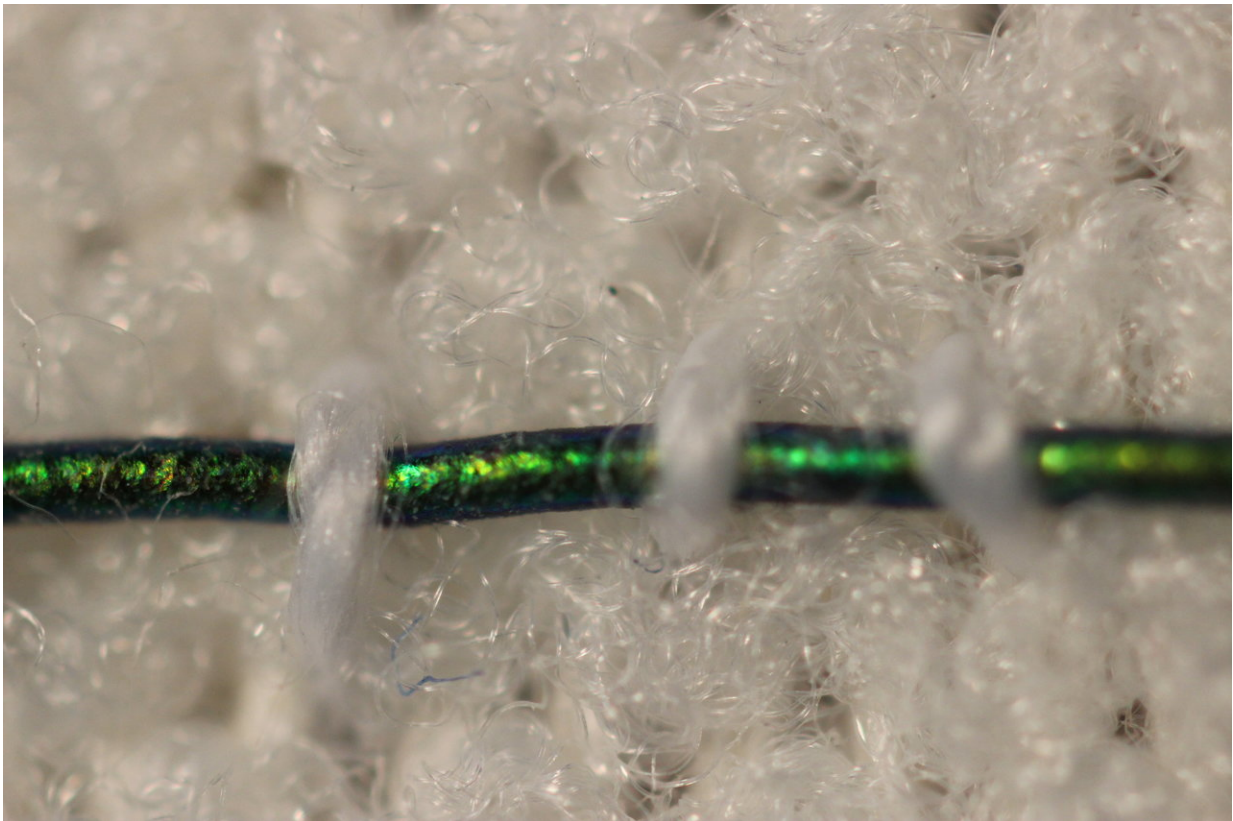


Engineers design color-changing compression bandage

May 29 2018, by Jennifer Chu



Engineers at MIT have developed pressure-sensing photonic fibers that they have woven into a typical compression bandage. Credit: Massachusetts Institute of Technology

Compression therapy is a standard form of treatment for patients who

suffer from venous ulcers and other conditions in which veins struggle to return blood from the lower extremities. Compression stockings and bandages, wrapped tightly around the affected limb, can help to stimulate blood flow. But there is currently no clear way to gauge whether a bandage is applying an optimal pressure for a given condition.

Now engineers at MIT have developed pressure-sensing photonic fibers that they have woven into a typical compression [bandage](#). As the bandage is stretched, the fibers change [color](#). Using a color chart, a caregiver can stretch a bandage until it matches the color for a desired pressure, before, say, wrapping it around a patient's leg.

The photonic fibers can then serve as a continuous pressure sensor—if their color changes, caregivers or patients can use the color chart to determine whether and to what degree the bandage needs loosening or tightening.

"Getting the pressure right is critical in treating many medical conditions including venous ulcers, which affect several hundred thousand patients in the U.S. each year," says Mathias Kolle, assistant professor of mechanical engineering at MIT. "These fibers can provide information about the pressure that the bandage exerts. We can design them so that for a specific desired pressure, the fibers reflect an easily distinguished color."

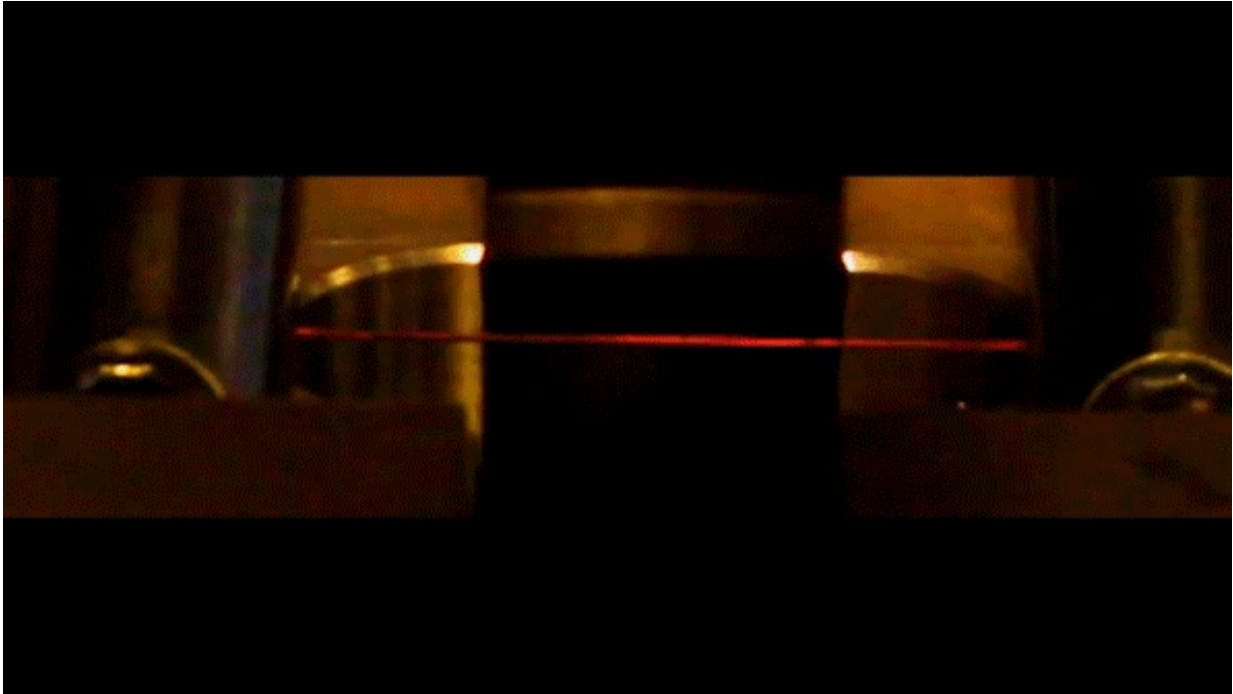
Kolle and his colleagues have published their results in the journal *Advanced Healthcare Materials*. Co-authors from MIT include first author Joseph Sandt, Marie Moudio, and Christian Argenti, along with J. Kenji Clark of the University of Tokyo, James Hardin of the United States Air Force Research Laboratory, Matthew Carty of Brigham and Women's Hospital-Harvard Medical School, and Jennifer Lewis of Harvard University.

Natural inspiration

The color of the photonic fibers arises not from any intrinsic pigmentation, but from their carefully designed structural configuration. Each fiber is about 10 times the diameter of a human hair. The researchers fabricated the fiber from ultrathin layers of transparent rubber materials, which they rolled up to create a jelly-roll-type structure. Each [layer](#) within the roll is only a few hundred nanometers thick.

In this rolled-up configuration, light reflects off each interface between individual layers. With enough layers of consistent thickness, these reflections interact to strengthen some colors in the visible spectrum, for instance red, while diminishing the brightness of other colors. This makes the fiber appear a certain color, depending on the thickness of the layers within the fiber.

"Structural color is really neat, because you can get brighter, stronger colors than with inks or dyes just by using particular arrangements of transparent materials," Sandt says. "These colors persist as long as the structure is maintained."



Credit: Massachusetts Institute of Technology

The fibers' design relies upon an optical phenomenon known as "interference," in which light, reflected from a periodic stack of thin, transparent layers, can produce vibrant colors that depend on the stack's geometric parameters and material composition. Optical interference is what produces colorful swirls in oily puddles and soap bubbles. It's also what gives peacocks and butterflies their dazzling, shifting shades, as their feathers and wings are made from similarly periodic structures.

"My interest has always been in taking interesting structural elements that lie at the origin of nature's most dazzling light manipulation strategies, to try recreating and employing them in useful applications," Kolle says.

A multilayered approach

The team's approach combines known optical design concepts with soft materials, to create dynamic photonic materials.

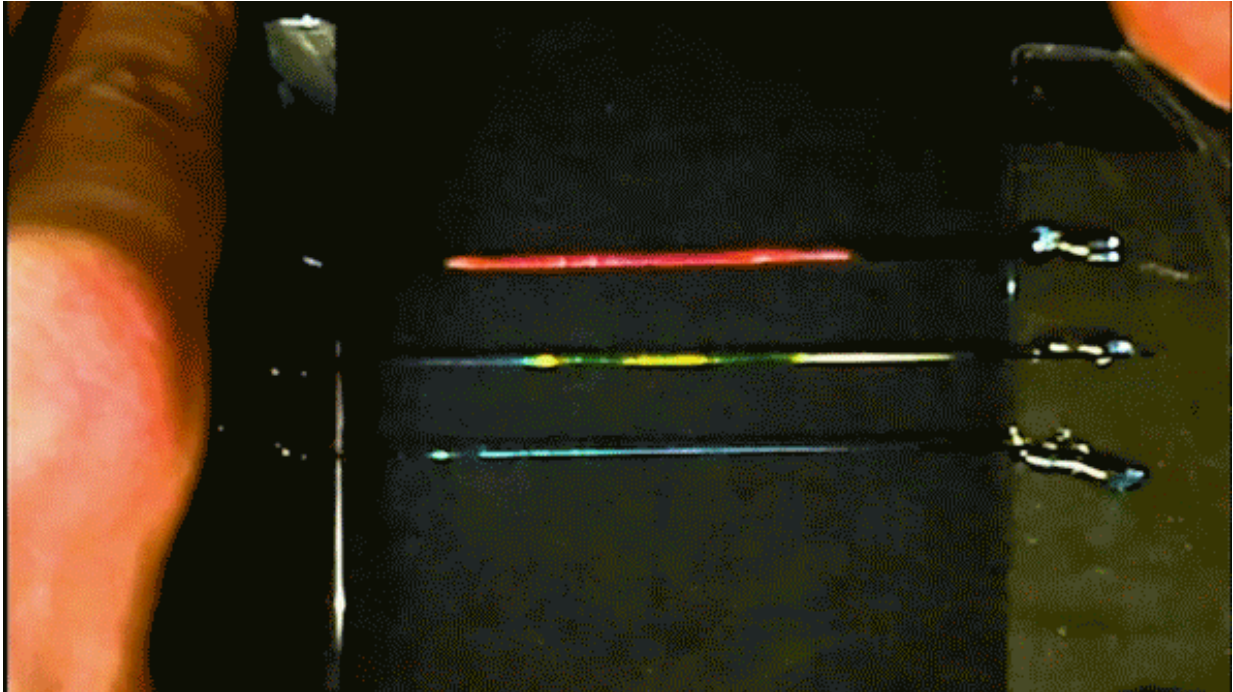
While a postdoc at Harvard in the group of Professor Joanna Aizenberg, Kolle was inspired by the work of Pete Vukusic, professor of biophotonics at the University of Exeter in the U.K., on *Margaritaria nobilis*, a tropical plant that produces extremely shiny blue berries. The fruits' skin is made up of cells with a periodic cellulose structure, through which light can reflect to give the fruit its signature metallic blue color.

Together, Kolle and Vukusic sought ways to translate the fruit's photonic architecture into a useful synthetic material. Ultimately, they fashioned multilayered fibers from stretchable materials, and assumed that stretching the fibers would change the individual layers' thicknesses, enabling them to tune the fibers' color. The results of these first efforts were published in *Advanced Materials* in 2013.

When Kolle joined the MIT faculty in the same year, he and his group, including Sandt, improved on the photonic fiber's design and fabrication. In their current form, the fibers are made from layers of commonly used and widely available transparent rubbers, wrapped around highly stretchable fiber cores. Sandt fabricated each layer using spin-coating, a technique in which a rubber, dissolved into solution, is poured onto a spinning wheel. Excess material is flung off the wheel, leaving a thin, uniform coating, the thickness of which can be determined by the wheel's speed.

For fiber fabrication, Sandt formed these two layers on top of a water-soluble film on a silicon wafer. He then submerged the wafer, with all three layers, in water to dissolve the water-soluble layer, leaving the two rubbery layers floating on the water's surface. Finally, he carefully rolled the two transparent layers around a black rubber fiber, to produce the

final colorful photonic fiber.



Credit: Massachusetts Institute of Technology

Reflecting pressure

The team can tune the thickness of the fibers' layers to produce any desired color tuning, using standard optical modeling approaches customized for their fiber design.

"If you want a fiber to go from yellow to green, or blue, we can say, 'This is how we have to lay out the fiber to give us this kind of [color] trajectory,'" Kolle says. "This is powerful because you might want to have something that reflects red to show a dangerously high strain, or green for 'ok.' We have that capacity."

The team fabricated color-changing fibers with a tailored, strain-dependent color variation using the theoretical model, and then stitched them along the length of a conventional compression bandage, which they previously characterized to determine the pressure that the bandage generates when it's stretched by a certain amount.

The team used the relationship between bandage stretch and pressure, and the correlation between fiber color and strain, to draw up a color chart, matching a fiber's color (produced by a certain amount of stretching) to the pressure that is generated by the bandage.

To test the bandage's effectiveness, Sandt and Moudio enlisted over a dozen student volunteers, who worked in pairs to apply three different compression bandages to each other's legs: a plain bandage, a bandage threaded with photonic fibers, and a commercially-available bandage printed with rectangular patterns. This bandage is designed so that when it is applying an optimal pressure, users should see that the rectangles become squares.

Overall, the bandage woven with photonic fibers gave the clearest pressure feedback. Students were able to interpret the color of the fibers, and based on the color chart, apply a corresponding optimal [pressure](#) more accurately than either of the other bandages.

The researchers are now looking for ways to scale up the fiber fabrication process. Currently, they are able to make fibers that are several inches long. Ideally, they would like to produce meters or even kilometers of such fibers at a time.

"Currently, the fibers are costly, mostly because of the labor that goes into making them," Kollé says. "The materials themselves are not worth much. If we could reel out kilometers of these fibers with relatively little work, then they would be dirt cheap."

Then, such fibers could be threaded into bandages, along with textiles such as athletic apparel and shoes as color indicators for, say, muscle strain during workouts. Kolle envisions that they may also be used as remotely readable strain gauges for infrastructure and machinery.

"Of course, they could also be a scientific tool that could be used in a broader context, which we want to explore," Kolle says.

More information: Joseph D. Sandt et al. Stretchable Optomechanical Fiber Sensors for Pressure Determination in Compressive Medical Textiles, *Advanced Healthcare Materials* (2018). [DOI: 10.1002/adhm.201800293](https://doi.org/10.1002/adhm.201800293)

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